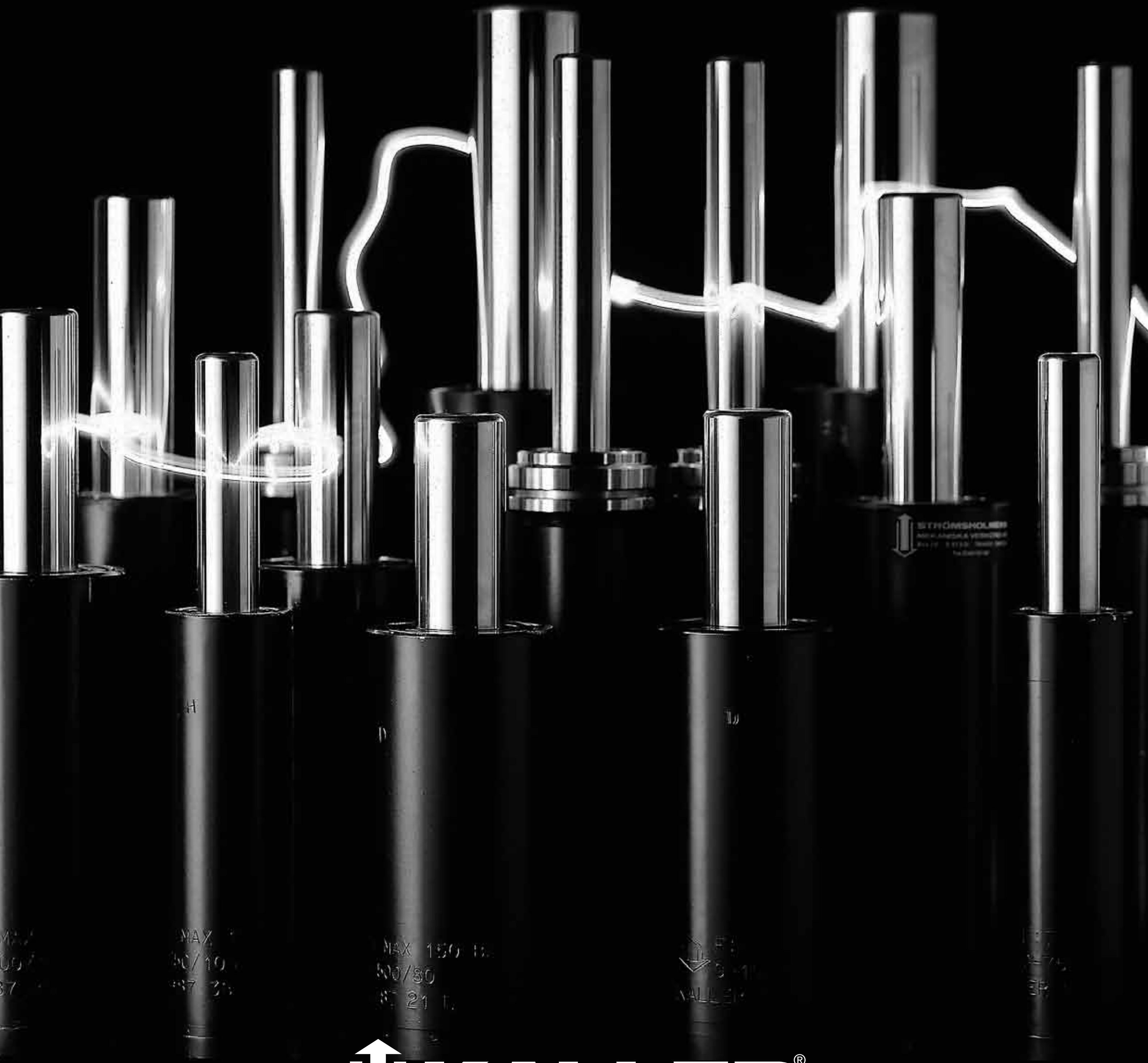
Basic Gas Spring Theory



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Calculating the initial force

The initial force of the gas spring can be calculated as the sealed area of the piston rod or the piston (depending on design) multiplied by the pressure inside the gas spring.

The larger the effective cross sectional area of the piston rod or the piston, the more ”powerful” the gas spring will be. This explains why a Bore Sealed spring, like the CU spring is more powerful than a Piston Rod Sealed spring, like the TU spring with the same outer body diameter. Derived from the information above the gas spring force can be written as:

Formula ❶

$$F_{\text{gas spring}}\ (N) = p \cdot d_{\text{seal}}^{2} \cdot \frac{\pi}{40}$$

p (bar) = Charge Pressure
d_{seal} (mm) = Dynamic Seal Diameter

Adjusting the initial force

As seen from formula ❶ the force from any given gas spring can be changed by changing the gas pressure. In cases where a non standard initial force is required the following formula should be applied.

Formula ❷

$$p_{\text{charging}} = p_{\text{standard}} \cdot \frac{F_{\text{required}}}{F_{\text{standard}}}$$

F_{required} (N) = The required initial force
F_{standard} (N) = Standard initial force (at p_{standard})
p_{standard} (bar) = Standard charging pressure

Example I

A TU 1500 spring (see page 2.6/24) should be modified to give an initial force of 12 000 N (at 20°C).

$$p_{\text{charging}} = p_{\text{standard}} \cdot \frac{F_{\text{required}}}{F_{\text{standard}}}$$

F_{required} = 12 000 N

In the table for the TU 1500 the following values can be found:

p_{standard} = 150 bar
F_{standard} = 15 000 N

The charging pressure that should be used will then be:

$$p_{\text{charging}} = 150 \cdot \frac{12\,000}{15\,000} = 120 \text{ bar}$$

A gas pressure of 120 bar will give the desired initial force of 12 000 N.

The standard initial force, F_{standard} and the standard charging pressure at 20°C are given for each model in the catalogue.

Isothermic force increase

As the gas spring is compressed the gas pressure inside the spring will rise resulting in an increased gas spring force. The gas pressure increase (and force increase) is determined by the following gas laws.

The ideal gas law

Formula ❸

$$p \cdot V = n \cdot R \cdot T$$

p (bar) = gas pressure
V (l) = gas volume
n (mole) = molecular quantity
R (Nm/°K) = gas constant = 8.314
T (°K) = temperature

For a closed system, as the gas spring, where the temperature is kept constant (isothermic process) this formula can be simplified to:

Formula ❹

$p \cdot V = \text{constant}$ (Boyles law)

Calculating the gas pressure at a certain point of the stroke (S) can be performed in the following way:

Formula ❺

$$p_o \cdot V_o = p_s \cdot V_s$$

p_o (bar)	= initial pressure
V_o (l)	= initial volume
p_s (bar)	= pressure at stroke S
V_s (l)	= volume at stroke S

By combining this Formula ❺ with Formula ❶ the following Formula ❻ can be derived to calculate the force at any position of the stroke.

Formula ❻

$$F_s = F_{init,\ actual} \cdot \left[\frac{S_{nom}}{S_{nom} - S_{used} \cdot \left(1 - \frac{F_{init,nom}}{F_{end,\ nom}}\right)} \right]$$

F_s (N)	= force at the used stroke S
$F_{init,actual}$ (N)	= initial force at current charging pressure
S_{used} (mm)	= used stroke
S_{nom} (mm)	= nominal stroke for the spring
$F_{init,nom}$ (N)	= nominal initial force of the spring
F_{end} (N)	= force at full nominal stroke

S_{nom}, $F_{init,nom}$ and $F_{end,nom}$ are given for each model in the catalogue. If the force has not been changed (the charge pressure has not been modified) $F_{init,\ actual}$ will be the same as the $F_{init,\ nom}$ which is the value given in the catalogue.

Note!
All end forces, stated in the catalogue are the isothermic end forces.

Example II

What is the spring force of a TU 1500–100 when compressing the spring 80 mm?

$$F_s = F_{init,\ actual} \cdot \left[\frac{S_{nom}}{S_{nom} - S_{used} \cdot \left(1 - \frac{F_{init,\ nom}}{F_{end,\ nom}}\right)} \right]$$

$S_{used} = 80$ mm

The table for the TU 1500 (see page 2.6/24) will give the following values:

$F_{init,\ actual} = 15\,000$ N
$S_{nom} = 100$ mm
$F_{init,\ nom} = 15\,000$ N
$F_{end,\ nom} = 23\,000$ N

$$F_s = 15\,000 \cdot \left[\frac{100}{100 - 80 \cdot \left(1 - \frac{15\,000}{23\,000}\right)} \right]$$

F_s (80 mm) = 20 800 N

If the temperature of the gas spring is kept constant, (isothermic process), the spring will give a force of 20 800 N when compressed 80 mm.

Polytropic force increase

For most applications the temperature inside the gas spring will not stay constant during the stroke. For these applications the following formula should be used to calculate the ”true” force increase (polytropic process).

Formula ❼

$$F_s = F_{init,\ actual} \cdot \left[\frac{S_{nom}}{S_{nom} - S_{used} \cdot \left(1 - \frac{F_{init,\ nom}}{F_{end,\ nom}}\right)} \right]^n$$

Where n is called the polytropic exponent.

Depending on how fast the gas spring is compressed and the initial gas pressure, the n-value will be between 1 and 1.55. For a normal application in a press tool and a charging pressure of 150 bar, a value of 1.4 can be used.

S_{nom}, $F_{init,nom}$ and $F_{end,nom}$ are given for each model in the catalogue. If the force has not been changed (the charge pressure has not been modified) $F_{init, actual}$ will be the same as the $F_{init, nom}$ which is the value given in the catalogue.

Note! All end forces, stated in the catalogue are the isothermic end forces.

Example III

What is the "polytropic" end force of a TU 1500-100, when using a stroke of 80 mm in a "normal" press application?

Formula ❼

$$F_{s, polytropic} = F_{init, actual} \bullet \left(\frac{S_{nom}}{S_{nom} - S_{used} \bullet \left(1 - \frac{F_{init, nom}}{F_{end, nom}}\right)} \right)^{n}$$

$F_{init, actual}$ = 15 000 N
S_{nom} = 100 mm
S_{used} = 80 mm
$F_{end,nom}$ = 23 000 N
$F_{init,nom}$ = 15 000 N
n = 1.4 ("normal press application")

$$F_{s, polytropic}(80\ mm) = 15\,000 \bullet \left(\frac{100}{100 - 80 \bullet \left(1 - \frac{15\,000}{23\,000}\right)} \right)^{1.4}$$

$F_{s, polytropic}$ (80 mm) = 23 700 N

Initial force depending on temperature

The temperature of the nitrogen gas affects the pressure in, and the force of, the gas spring. The forces given in the catalogue are based on a temperature of 20°C. Using the same basic Formula ❸ as before the pressure and force at other temperatures can be calculated as follows:

Formula ❽

$$\frac{p_0}{T_0} = \frac{p_1}{T_1}$$

T_0 (°K) = Reference temperature

T_1 (°K) = Gas spring temperature

Formula ❾

$$p_1 = p_0 \bullet \frac{T_1}{T_0}$$

As the force is proportional to the pressure, it can also be written as:

Formula ❿

$$F_1 = F_0 \bullet \frac{T_1}{T_0}$$

Example IV

A gas spring with a initial force of 15000 N at 20°C is used in such a way that the gas spring temperature is increased to 60°C. What initial force will the spring have at 60°C?

Solution using Formula ❿

$$F_1 = F_0 \bullet \frac{T_1}{T_0}$$

F_0 = 15 000 N

T_1 = 273 + 60°C = 333°K

T_0 = 273 + 20°C = 293°K

$$F_1 = 15\,000 \bullet \frac{333}{293} = 17\,000\ N$$

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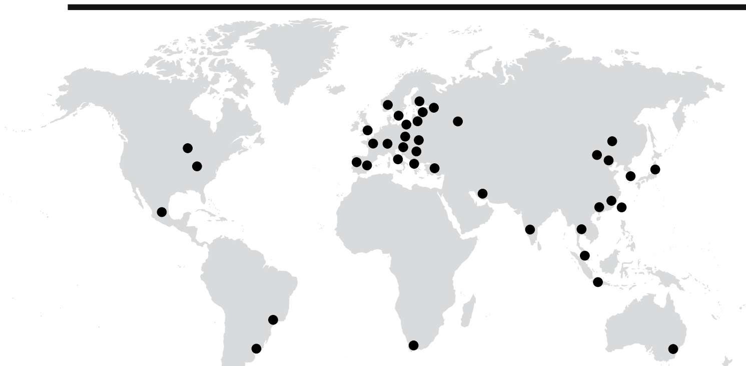

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